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X-RAY OBSERVATIONS OF THE SEYFERT I GALAXIES AKN120 AND MCG8-11-11

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ABSTRACT

We identify a new X-ray source, H0523-00, with the optically variable Seyfert I galaxy AKN120. The source has a 2-10 keV X-ray flux of $\sim 2 \times 10^{-11}$ ergs/cm^2 s which corresponds to a 2-10 keV X-ray luminosity of $L_x \sim 1 \times 10^{44}$ ergs/sec. X-ray observations over a 1.5 year time span combined with contemporaneous optical photometry (Miller 1979a) show a decrease in the optical with no corresponding decrease in the X-ray. In contrast, similar observations of MCG8-11-11 show a contemporaneous decrease in optical and X-ray fluxes. We note that the infrared and X-ray spectral slopes for these two objects are similar with the optical being steeper by $\sim$ one unit.

Keywords:
Galaxies:Seyfert,X-Rays:Sources,X-Rays:Spectra

I. INTRODUCTION

There has been until now very little data on X-ray-optical variability in Seyfert I galaxies. Using a combination of 4U and 2A data Lyuti (1978) has claimed a positive correlation between the optical and X-ray flux of NGC4151. We are aware of no other relevant observations.

Elvis et al. (1977) have shown that X-ray luminosity is correlated with several optical properties of Seyfert I galaxies. In particular there is a strong trend for optically luminous Seyfert I nuclei to be luminous X-ray sources. One might therefore expect that the X-ray and optical fluxes to be related to each other.

The optical emission from a Seyfert I nucleus is a combination of line emission, thermal bremsstrahlung from a hot gas and a presumably "non-thermal" component. It is the "non-thermal" component that probably is closely related to the X-ray flux. However, the line strength and the hot gas emission are caused by photoionization (Osterbrock 1979) induced by the "non-thermal" ultra-violet radiation and thus should vary if the "non-thermal" component varies but on a different timescale.

It is therefore not entirely clear what is to be expected to be the relationship between broadband optical continuum fluxes (e.g. UBV photometry) and X-ray fluxes. In this paper we report X-ray observations taken contemporaneously with optical UBV photometry (Miller 1979a,b) for 2 Seyfert I galaxies, AKN120 and MCG8-11-11, and find that these two objects behaved differently.

II. OBSERVATIONS

A. AKN120

The HEAO-1 satellite experiment A-2[1] (Rothschild et al. 1979) scanned the region containing the Seyfert I galaxy AKN120 (Arakelian 1975; Osterbrock and Phillips 1977) on 3 occasions (Table 1) from Sept. 1977 to Sept. 1978.

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[1]The A2 experiment on HEAO-1 is a collaborative effort led by E. Boldt of GSFC and G. Garmire of CIT, with collaborators at GSFC, CIT, JPL and UCB.

On each occasion a statistically significant detection of a new source H0523-00 was obtained. The 90% confidence error box, derived from the second observation (1978 D66-71) was constructed following the prescription of Marshall et al. (1979). The error box (box 2 of Marshall et al (1979)) has an area of .5 sq. deg and contains AKN120. Since Seyfert I galaxies are a well established class of X-ray sources (Elvis et al. 1978; Dower et al. 1980; Marshall et al. 1979) we identify the X-ray source with AKN120.

B. MCG8-11-11

MCG8-11-11 has been firmly established as an X-ray emitting Seyfert I galaxy (Ward et al. 1978; Dower et al. 1980). This source was observed on 3 occasions by HEAO-1 experiment A-2 (Table 2). Previous HEAO-1 results on the time variability of this source have been reported by Mushotzky et al. (1980).

III. RESULTS

A. Spectrum and Flux

i) AKN120:

Because this source is quite weak and data exist only from the scanning mode we have relatively poor statistics on the X-ray spectrum. The best fit power law of the form $\frac{dN}{dE} = A E^{-\alpha} \exp(-\sigma N_H)$ keV/cm^{2}sec keV has $A \simeq 6 \times 10^{-3}$, $\alpha = 0.7$ (+0.9,-0.4) (68% confidence error) and $N_H \leq 7 \times 10^{22}$ at/cm^2.

This is consistent with the average X-ray spectrum of Seyfert I galaxies (Mushotzky et al. 1980). The intergral flux in the 2-10 keV band for the first two observations corresponds to a 2-10 keV luminosity of 1.2×10^{44} ergs/sec (H_0 = 50 kms^{-1} Mpc^{-1}). The ratio of optical V band luminosity to X-ray luminosity, L_V/L_X, is ~ 0.4. The X-ray luminosity and optical to X-ray luminosity ratio are typical of X-ray emitting Seyfert I galaxies (Mushotzky et al. 1980b) if the identification is correct. This consistency lends further support to our proposed identification.

ii) MCG8-11-11:

The spectrum is well fit by a power law (Mushotzky et al. 1980) of energy index α = 0.6 (+.3,-.2) with no low energy absorption. The integral flux during the first observation of 4.6×10^{-11} ergs/cm^2 sec corresponds to a 2-10 keV luminosity of 8.3×10^{43} ergs/sec. It has $L_V/L_X \sim .2$ using the contemporaneous optical photometry of Miller (1979a).

B. Time Variability

i) AKN120

The counting rates for this source on a day to day basis for the 3 observations is shown in Figure 1. There is no evidence for any significant variability on this timescale. The average fluxes for the 3 separate observations (Table 1) show marginal evidence for variability on a 6 month timescale. χ^2_ν is 1.5 for a constant source model. Since χ^2_ν would be this large $\sim$ 23% of the time with no real variability, we do not claim to have detected source variability. The data do provide an upper limit of $\sim$ 30% on 6 month variability of Akn120 at the 90% confidence level.

The 2σ upper limit from Ariel 5 data of 3.1×10^{-11} ergs/cm^2 sec in the 2-10 keV band (Elvis et al. 1978) and the 2.5σ PST detection of $1.9 \pm 0.7 \times 10^{-11}$ ergs/cm^2 sec in the 2-10 keV band from Uhuru (Tananbaum et al. 1978; this source was not a line of position detection in the 4U catalog) do not place strong constraints on the source variability.

ii) MCG8-11-11

This source has been reported to be variable by Ward et al. (1978) on a time scale of $\sim$ 30 days. Our first scan flux of 4.6×10^{-11} ergs/cm^2 sec disagrees at the 4.7σ level from the value of $\sim 2 \times 10^{-11}$ ergs/cm^2 sec on the 2nd and 3rd scans (Table 2). These fluxes compare with the range of $<2 \times 10^{-11}$ to 8×10^{-11} ergs/cm^2 sec reported by Ward et al. The day to day count rates from this source are shown in Figure 2 and no evidence for variability on a day to day time scale is detected.

IV. COMPARISON WITH OPTICAL DATA

A. X-Ray and Optical Variability

i) AKN120

Miller (1979b) and Puschell (1978) have observed AKN120 at times bracketed by our X-ray observations. Miller reports a brightening of the B magnitude of AKN120 by 0.30 mag from 1977 Day 283 to 1978 Day 12 with no change in the U-B or B-V colors. The source dimmed by $\Delta B = 0.62$ mag from 1978 Day 36 to 1978 Day 267 with a change in the U-B and B-V colors. No significant variability was noted on timescales less than 4 days.

If one constructs power law spectra from the UBV colors following Matthews and Sandage (1963), ignoring the effects of line emission and reddening, one finds a change in spectral index $\Delta\alpha = 0.5$ from 78 Feb to 78 September; that is the optical continuum was <u>flatter</u> when it was brighter.

The X-ray data seem uncorrelated with the optical continuum variability. While the optical brightened by $\sim$ 30% from 77 Oct to 78 March the X-ray showed no measurable change (+10% $\pm$ 23%). From 78 March to 78 September the optical flux <u>decreased</u> by $\sim$ 60% while the X-ray data indicate a possible <u>increase</u> of 25% $\pm$ 24%. The X-ray data rule out a decrease of 60% at greater than the 3σ level.

It thus seems that in this source changes in the X-ray and optical are uncorrelated or even possibly anti-correlated during the decline in the optical flux. During the increase in the optical emission the X-ray had, at most, a similar percentage increase. Because only a fraction of the total U band flux comes from the "non-thermal" continuum this indicates that, during the optical increase, the X-ray's emission underwent a smaller increase then the "non-thermal" optical continuum.

ii) MCG8-11-11

Miller reports that the nucleus of this source exhibited a decrease in its B magnitude of $\Delta B \sim .45$ mag between 10 Oct 1977 (Day 283) and 4 March 1978 (Day 63). During this period the X-ray flux decreased from 4.6 to 1.8 x

10^{-11} ergs/cm^2 sec in the 2-10 keV band (Table 2). The ratio of the fluxes in the B band was $R = I_1/I_2 = 1.51 \pm .02$ while in the X-ray it was $R = 2.52 \pm .73$. Therefore evidence exists in this source for correlated X-ray-optical variability with similar amplitudes for change in both frequency bands.

B. Optical and X-ray Spectra

i) AKN120

The infrared-optical continuum spectrum of AKN120 is not well fit by a single power law (see the data presented in Puschell (1978)). We have fit a 2 power law continuum to the optical and IR data of Puschell (1978) and Osterbrock and Phillips (1977) excluding the wavelength range around the 3200 Å "blue bump" (this bump can be considered as an emission feature (Kwan and Krolik 1979)) and derive a best fit IR power law over the 3.5 - 1.2μ wavelength range, of $\alpha \approx 0.6 \pm 0.2$ and an optical power fit in the .7μ - .39μ range of $\alpha_{opt} \cong 1.6 \pm 0.1$. These values compare with the X-ray slope in the 2-20 keV band of $\alpha_x \sim 0.7$ (+0.9,-0.4). It thus seems likely that the X-ray has a spectral slope similar to the IR band while the optical has a slope approximately 1 index steeper.

During the change in the optical flux Miller has noted changes in the (U-B), (B-V) colors of this source. If one constructs a power law optical spectrum to account for the UBV colors as above (ignoring the effects of emission lines and internal reddening) one finds no change, $\Delta\alpha_{opt} \approx 0$, during the optical brightening from 77 October to 78 March and a steepening, $\Delta\alpha = 0.5$, from 78 February to 78 September. The X-ray data are rather poor and cannot constrain a similar change in the X-ray spectrum even though there is no positive evidence for such a change.

ii) MCG8-11-11

We have performed a similar 2 power law deconvolution based on the optical data of deBruyn and Sargent (1979) and the IR data of McAlary, McLaren

and Crabtree (1979). The optical data fit a power law well with $\alpha_{opt} \approx 2.2 \pm 0.2$. The IR (1.2 - 4.6μ) data does not fit a power law well over this range with an excess evident in the 4.6μ band. A power law fit forced over this range gives a formal slope of $\alpha_{IR} = 0.9 \pm 0.2$. If one fits the 1.66 - 3.6μ data a power law is a good representation with $\alpha_{IR} = 0.5 \pm 0.3$. This compares to the 2-40 keV X-ray index for 77 Sept. of $\alpha_x = 0.65\ (+.3,-.2)$. So again we have evidence that the IR and X-ray have similar spectral slopes with the optical being one unit steeper.

Miller (1979b) notes a change in the UBV colors from 77 Oct to 78 March which corresponds to $\Delta\alpha = 0.5$, the same change as seen in AKN120. The X-ray spectral data for 78 March gives a best fit power law of 1.0 (+0.9,-0.4) 90% errors and $N_H < 6 \times 10^{22}$ at/cm^2 which agrees, within errors, with the spectrum of the prior observation. Thus there is no evidence for an X-ray spectral change but an increase in index of $\Delta\alpha \approx 1$ cannot be ruled out.

C. Optical and X-Ray Correlations

1) Hα vs. L_x

Phillips et al. (1979) have noted a strong correlation between the Hα and X-ray luminosities of Seyfert galaxies. For AKN120, which has a Hα luminosity of 3×10^{43} ergs/sec this relationship, $\log L_x \approx 12.0 + .75 \log L(H\alpha)$, would predict an 2-10 keV X-ray luminosity of $\sim 4 \times 10^{44}$ ergs/sec which is a factor of 4 higher than the observed luminosity; alternatively the X-ray flux would predict $L(H\alpha) \sim 5 \times 10^{42}$: this result places AKN120 at the edge of the (L_x, L(Hα)) distribution. For MCG8-11-11 integration of the deBruyn-Sargent fluxes yields $L(H\alpha) \sim 2.5 \times 10^{42}$ ergs/sec. The Phillips et al. relation predicts $L_x \sim 6 \times 10^{43}$ ergs/sec which brackets the observed X-ray flux range of $3\text{-}8 \times 10^{43}$ ergs/sec.

ii) Broadband Optical vs. X-ray

Elvis et al. (1977) have tabulated the ratio of flux in the V band to the X-ray flux for a sample of 11 seyfert galaxies which indicates that sources brighter in the V band tend to be brighter in the X-ray. Using a bandwidth of 1.5×10^{14} Hz for the U, B and V bands we calculate in Table 2 the ratio of optical to X-ray flux for the various observations using the data of Miller and the X-ray data closest in time to the optical observation. We note that for these two sources the X-ray/optical ratio differ by ~ 3 and that this ratio can change by ~ 2 for a given source. Elvis et al. (1978), Glass (1979) and McAlary, McLaren and Crabtree (1979) have all pointed out a correlation between 3.4μ and 2-10 keV fluxes (see McAlary et al., Fig. 2). The best fit power law relationship to the data of McAlary et al. gives a slope of 1 and F(X-ray) = 14.0 + F(3.5μ) with units of W/m^2 Hz for the IR flux and W/m^2 for the 2-10 keV X-ray flux. For AKN120 its observed 3.5μ flux of 61 mJy (Puschell 1978) would predict an X-ray flux of 6.1×10^{-11} ergs/cm^2 sec. This overestimates the X-ray flux by a factor of 3. This is consistent with the Hα vs. L_x and L_v/L_x relations which also tend to predict a stronger X-ray flux from the observed optical properties of this object. For MCG8-11-11 the predicted X-ray flux from its observed IR flux of 77 mJy (McAlary et al. 1979) of 5×10^{-11} ergs cm^2 sec agrees well with our measured X-ray flux.

V. DISCUSSION

The observation that the X-ray and optical fluxes from variable Seyfert galaxies can be both correlated and uncorrelated combined with the optical, IR and X-ray spectrum for these objects enables one to place constraints on specific models of emission for these objects. We shall restrict our discussion to two of them: the synchrotron self-Compton (SSC) model (Mushotzky 1976) and the thermal Compton model (TC) as developed by Katz (1977). (This is to simplify the discussion and is <u>not</u> to imply that other possible models are not valid).

Katz's model was developed to explain variable optical radiation from active galactic nuclei while avoiding excessive X-ray and gamma ray fluxes from multiple Compton scatterings. The "non-thermal" emergent flux is produced by Compton scattering a source of soft photons by a spherical cloud of hot electrons. An approximate power law spectrum is observed for energies between the energy of the soft input photons and the energy of the hot electrons with the spectral index depending on the optical depth of the cloud. Such a model is inconsistent with the observed X-ray, optical and IR properties of AKN120 and MCG8-11-11 for the following reasons. 1) The optical spectra are softer than the X-ray spectra. This would only happen if the X-ray flux were part of a Wein peak, but no Wein peak is produced in Katz's model for the observed optical power law index. 2) For AKN120, a decrease was observed in the optical with no accompanying decrease in the X-ray. This would require a hardening of the spectrum (due to an increase in the optical depth), but actually the optical spectrum was observed to soften. This is <u>not</u> to indicate that, perhaps, more sophisticated thermal-Compton models (Maraschi et al. 1979) cannot explain our results. At present, however, such models have not yet yielded observational parameters with which we can compare our data.

The SSC model (Mushotzky 1976) produces X-ray emission by inverse Compton scattering of synchrotron photons off the relativistic electrons that produce them. In this model the synchrotron spectrum has a power law shape over a large frequency range (ν_1 to ν_2). Above ν_2 there is a steepening (break) of the spectrum by 1 unit due to Compton and synchrotron energy losses of the initial relativistic electron distribution. At frequencies less then ν_1 the spectrum turns down due to synchrotron self absorption. The model predicts that the X-ray spectrum will, in general, have the same slope as the unbroken part of the synchrotron spectrum.

We see that for AKN120 and MCG8-11-11, if we assign the infrared emission to the unbroken part of the synchrotron emission and the optical to the one unit steeper part, that the SSC model can account for the observed continuum slopes.

As the source evolves from an initial injection of relativistic particles ν_2 decreases: e.g. the optical spectrum should get steeper (on the average), however unless the lower frequency synchrotron emission changes (due to adiabatic expansion for example (Mushotzky et al. 1978)) the X-ray flux in general would not change. Thus we could have optical "non-thermal" continuum variability with no X-ray flux change. This model would also predict that the highest optical frequencies (U Band) would show the greatest variability ; this seems to be the case (Penfold 1979).

In a general way, however, the X-ray and IR fluxes should be correlated since the X-ray flux is related in the SSC model to the IR flux (see Marscher et al. 1979 for the general relation). This might account for the good correlation between IR and X-ray flux and a general correlation between optical and X-ray fluxes as noted by Elvis et al.

In addition the SSC model would predict a low frequency turnover in the IR spectrum which observations of both the radio and IR fluxes of Seyfert I's (Wilson 1978) seem to require. Positive correlations between X-ray and optical flares would be expected during times when fresh relativistic particles are injected and positive correlations between optical and X-ray declines are expected when the flat part of the synchrotron spectrum is depressed.

Because of the limited number of observations, we cannot rule out the possibility that the changes in optical and X-ray intensities are unrelated. Thus more extensive observations are needed to test models in which the optical and X-ray fluxes are separate components.

VI. CONCLUSION

A new X-ray source H0523-00 has been identified with the Seyfert 1 galaxy AKN120. Contemporaneous optical and X-ray measurements show an event with a

decrease in optical flux but no decrease in the X-ray flux. Similar observations of MCG8-11-11 found a decrease in both the optical and X-ray intensities.

The IR, optical, and X-ray spectra as well as the temporal variability are consistent with a synchrotron self-Compton origin of the non-thermal flux in these objects. The data are not consistent with the thermal-Compton model of Katz. Further contemporaneous multiple waveband observations are required to test whether the two events reported here are characteristic of active galactic nuclei.

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TABLE 1: AVERAGE X-RAY FLUXES FOR AKN120 FOR MCG8-11-11

2-10 keV Flux (10^{-11} ergs/cm^{2}sec)	Date (Year, Day of Year)		Observation Number
a) AKN120			
2.31 ± 0.30	1977	252-256	1
2.55 ± 0.43	1978	66-71	2
3.20 ± 0.42	1978	252-256	3
b) MCG8-11-11			
4.60 ± .28	1977	263-266	1
1.82 ± .52	1978	77-81	2
2.29 ± .52	1978	263-266	3

TABLE 2: RATIO OF U, B, V BAND FLUX TO 2-10 keV X-RAY FLUX

OBJECT	OBSERVATION #	U/L_x	B/L_x	V/L_x
AKN120	1	.46	.47	.57
	2	.52	.56	.71
	3	∿.27[a]	∿.32[a]	∿.50[a]
MCG8-11-11	1	∿.043[b]	∿ .10[b]	∿.18[b]
	2	.072	.17	.32

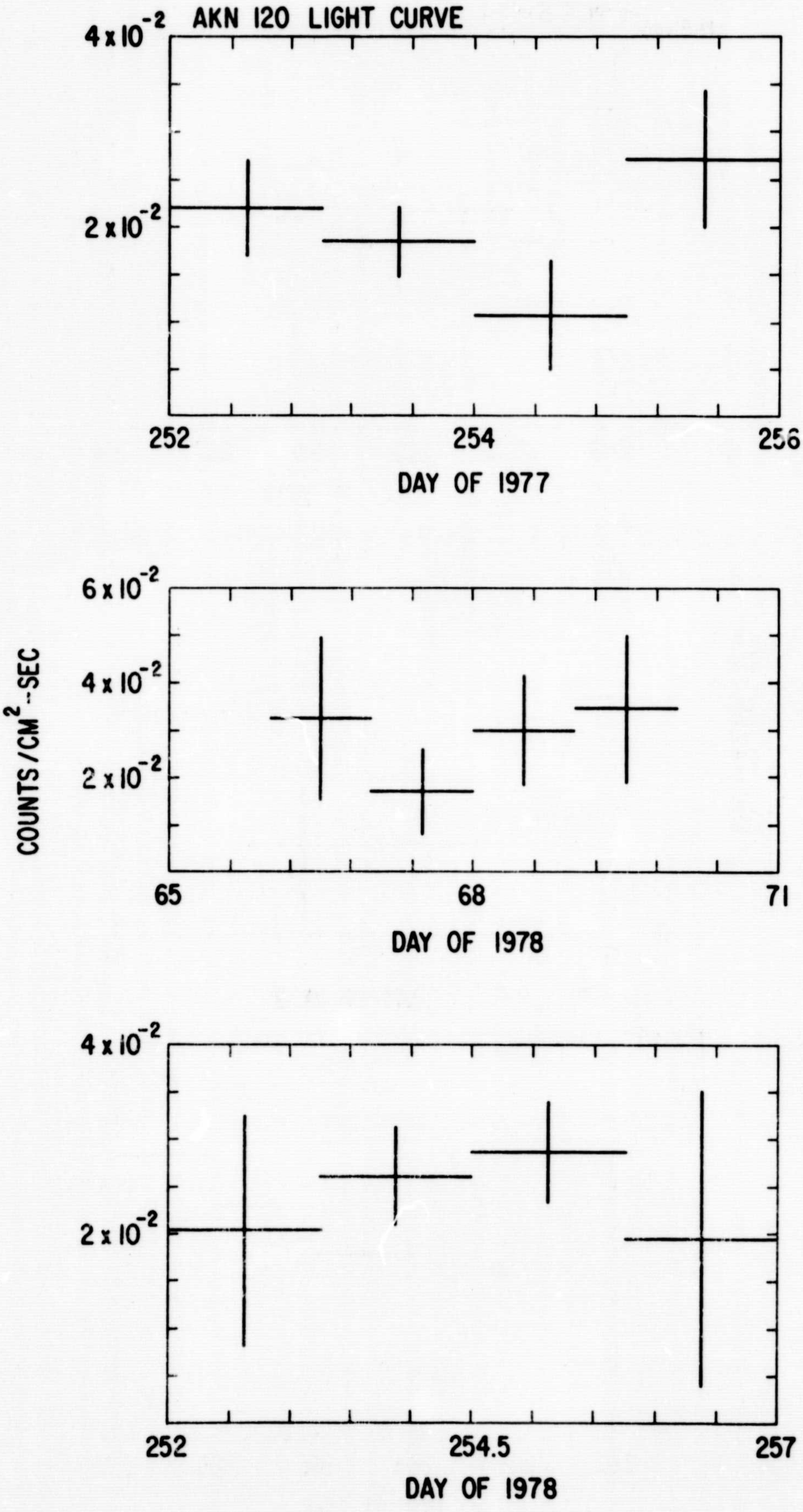
[a] From photographic data

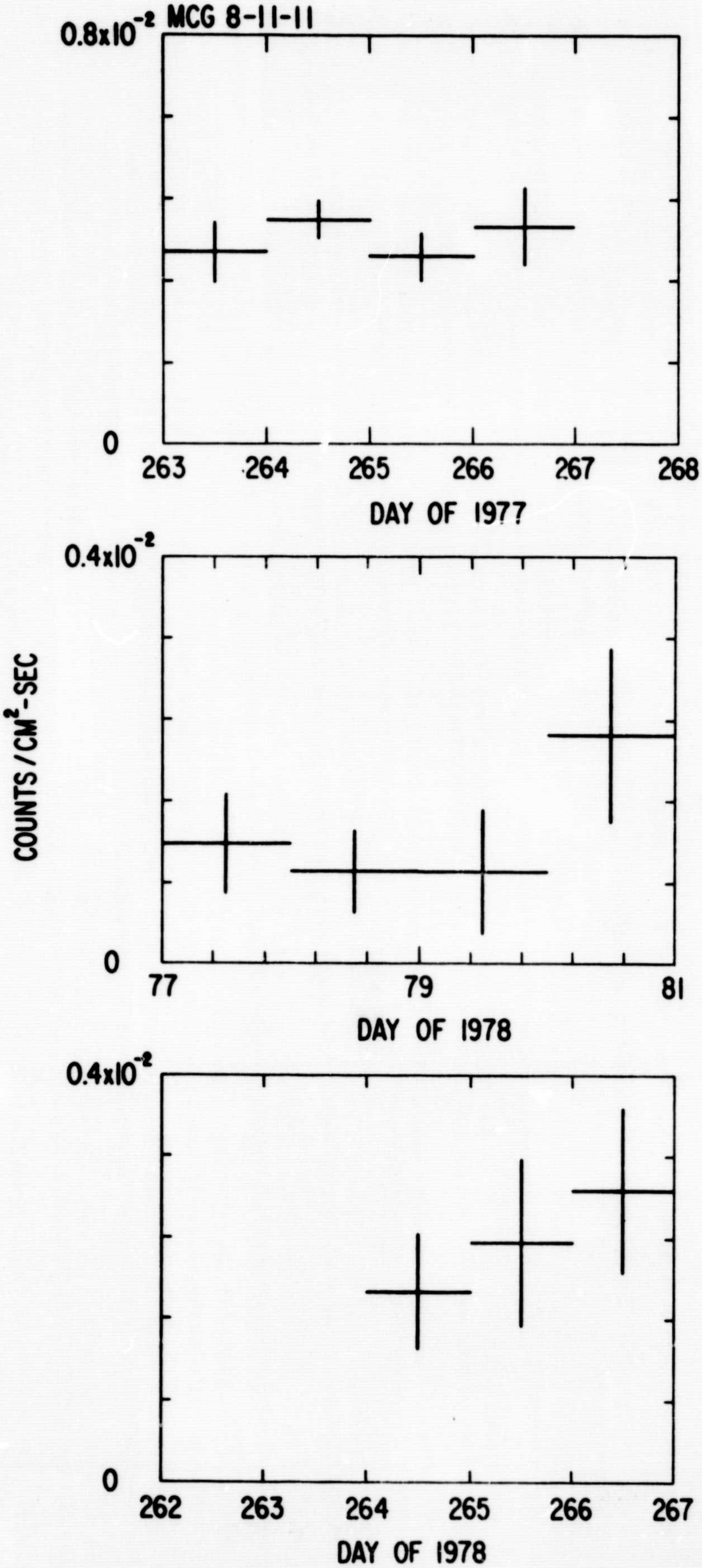
[b] From Oct. 10 data of Miller (1979a)

FIGURE CAPTIONS

Figure 1 - The X-ray light curves for the 3 observations of AKN120. The data are averaged over 1 day intervals and the X-ray fluxes are in counts/cm^2 sec.

Figure 2 - The X-ray light curves for the 3 observations of MCG8-11-11. The data are averaged on 1 day intervals and the X-ray fluxes are in units of counts/cm^2 sec.


AKN 120 LIGHT CURVE
4 x 10^-2
2 x 10^-2
252
254
256
DAY OF 1977
6 x 10^-2
4 x 10^-2
2 x 10^-2
COUNTS/CM^2-SEC
65
68
71
DAY OF 1978
4 x 10^-2
2 x 10^-2
252
254.5
257
DAY OF 1978



MCG 8-11-11
0.8x10^-2
0
263
264
265
266
267
268
DAY OF 1977
0.4x10^-2
0
77
79
81
DAY OF 1978
COUNTS/CM^2-SEC
0.4x10^-2
0
262
263
264
265
266
267
DAY OF 1978

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